Reprinted from

URBAN DISCHARGES AND RECEIVING WATER QUALITY IMPACTS

Edited by

J. B. ELLIS

PERGAMON PRESS
OXFORD · NEW YORK · BEIJING · FRANKFURT
SÃO PAULO · SYDNEY · TOKYO · TORONTO
1989
BIOLOGICAL ASSESSMENT OF EFFECTS OF COMBINED SEWER OVERFLOWS AND STORM WATER DISCHARGES

L. Lijklema, R. M. M. Roijackers and J. G. M. Cuppen

Water Quality Management Section, Dept. of Nature Conservation, Agricultural University, P. O. B. 8080, 6700 DD Wageningen, The Netherlands

ABSTRACT.
The biological effects of discharges from combined or separated sewer systems are difficult to assess or to predict due to variabilities in concentrations, environmental conditions, morphometry, susceptibility of organisms, seasonality and other factors. A general discussion of the problem results in an outline of two approaches. The first approach is to generalize field experiences and some examples of results are presented and explained. Notably site-specific conditions are shown to overshadow effects of discharges for many of the biological components in the ecosystem. The second approach is to perform toxicity tests which account for the temporal and spatial scales encountered in the field and for the relevant concentration levels.

KEYWORDS
Biological effects; bio-indicators; acute toxicity; chronic toxicity; combined sewer overflows; storm water; multivariate analyses; temporal scales; spatial scales.

INTRODUCTION
Increasingly waste-waters are being treated before discharge into receiving waters. Concomitantly the relative contribution of the remaining sources of pollution increases and more attention to their effects is paid in research and control. Among these sources the discharges from combined and separated sewer systems are frequently important, especially near urban or industrial areas. The effects of combined sewer overflows or storm water discharges upon the receiving waters are inherently transient in nature, and it has been recognised that physical and chemical characteristics of the discharges or the receiving water as such provide limited insight into the potentially detrimental effects on the level of populations of aquatic organisms or of the ecosystem. Mathematical modeling has contributed significantly to the insight into the frequency distribution of physico-chemical effects, but biological effects are still poorly amenable to prediction by modeling. Hence techniques, or rather approaches to assess harmful effects on the biota, are much in demand as the loss of function of the receiving water at least partially is related to the biological quality.

1 SEP. 1989
OBJECTIVES

The objective of this paper is to discuss and illustrate how potential harmful effects of CSOs and storm water discharges can be assessed at the population and ecosystem level and predicted by appropriate tests, the use of bioindicators and the generalisation of field experiences.

DISCUSSION OF THE PROBLEM

Various and complicated problems are encountered when this task is considered. The complexity is due to:

- the variability in time, space and intensity of the loading and the concomitant effects
- the variety of processes affecting water quality determinants and the wide range of time constants for these processes
- the complex and variable composition of the discharged polluted water
- the differences in susceptibility to adverse environmental conditions for the various organisms living in water or sediments in relation to their specific life cycles, habitat selection, feeding habits etc.
- the seasonal and other variations in environmental conditions and the natural response of populations and ecosystems to such variation even in the absence of any pollution
- the variability due to differences in morphometry, sediment and water properties, flow regimes, dilution rates and other relevant site-specific conditions.

These factors exert their influence upon the ultimate systems response in an interactive way. Some of these interactions are shown in Figure 1 in which the spatial and temporal scales of effects in receiving waters are shown qualitatively. These effects are the result of the interaction of processes in the receiving water (transport, sedimentation, decay) and of response times of species or communities. The figure is far from complete but it illustrates that the variability due to dynamic, high rate processes require a high frequency sampling or continuous monitoring in the vicinity of the outlet, whereas more chronic processes related with slow processes can be observed more or less apart from the individual storm event and on a wider spatial scale. From this it will be self-evident that biological indicators for immediate or more chronic effects should be selected on the basis of their generation time as a first criterion.

Further it will be clear that differences in flow conditions will dominate over other factors. This is already true for non-polluted systems: running waters have different communities than stagnant or semi-stagnant systems. Also the recovery of a system after a disturbance will depend strongly on the flow conditions and the opportunities for recolonisation from upstream areas.

Biological effects that can be expected to occur include:

- wash out of organisms with the water and scour of sediments (comparable to catastrophic drift);
- toxicity effects of micropollutants;
- reduction of DO resulting in die off of organisms;
- turbidity, reducing primary productivity, but also stimulation of plant growth by nutrient input, etc.

The duration and level of the adverse concentrations may lead to acute toxicity effects, but generally chronic effects due to prolonged exposure of microorganisms are more likely to occur than acute consequences. Low oxygen concentrations, however, can be expected shortly after an overflow event and can be very harmful for fish, particularly when these outfalls are well propped. Even prolonged exposure of fish to moderate deficits has been shown to have comparable effects. This has resulted in recommended standards for DO as a function of exposure time in Denmark (Halbach et al., 1986), which is probably too sophisticated for practical management. More important is the concept to relate standards to recurrence time as proposed by the same author. This concept is important in relation with the generation time of organisms: a long generation time requires a long return period for adverse conditions to become acceptable.

Ideally, impact studies would require controls in both time and space (Green, 1974). This is sometimes evidence for an effect must be based on changes that occurred in the test area, but not in the control area. Such a set up would allow for factorial design. However in the real world generally impacts have already occurred near the outlet, unless a new discharge is being studied. Hence a rigorous statistical approach is not possible. Gradients observed in the biotic community in the affected area may be used to interpret impacts.

As to the choice of indicator or test organisms, it will be evident from inspection of Figure 1 that more permanent effects can be expected to show up in the bottom dwelling organisms because in the sediments pollutants tend to accumulate and adverse conditions are more permanent. Short term effects would show up predominantly in short living organisms in the water phase. Fish, with their complex interactions in the food web and mobile character, would exhibit both acute and chronic effects. It should be noted that effects on the level of individual animals such as small changes in metabolic rates or yields may remain imperceptible, but they may show up in the next level of integration: population dynamics (Halbach, 1984). Extrapolation of this observation leads to the conclusion that no-effect levels will be even lower for the ecosystem. Hence interpretation of field data or test results on the level of isolated organisms or species should be made with caution.

Figure 1. Relation between the rates of processes and the spatial scale of the effects (from: Aalderink and Lijklema, 1985).

TWO APPROACHES

Considering the variability in time, space, effluent composition, the site-specific conditions and the lack of detailed knowledge of the interacting physical, chemical and biological processes, no uniform, simple and unbiased methodology is available to assess, to evaluate and to predict harmful effects on the biological system. In the opinion of the authors the problem can be approached from two different sides, each with their limitations but mutually more or less supplementary.
The first approach: Evaluation and generalization of field experiences.

The basic idea is that from a large data set of effects upon several organisms, including spatial and temporal gradients and different combinations of sewer system, morphometry of receiving water, season etc., a general insight can be obtained into the extent and duration of impacts. The conditions to be expected at a specific site can be inferred from the existing experience by analogy and compared to what is desirable and acceptable. Alternatively the position of an object in the reference framework can be assessed and compared and the changes to be expected from management measures indicated. The task involves the evaluation and interpretation of large data sets and the use of techniques that allow the discrimination between cause-effect relationships. Such an analysis also may indicate which organisms are suitable bio-indicators for impact analysis.

The second approach: Direct tests with indicator organisms. This approach is the classical testing of the effect of an effluent and/or the suspended solids on a test population or individual organism. This includes bio-assays in which the relative potency of a solution is compared with the effect of a standard solution (such as the assays used in eutrophication studies) and, more important here, toxicity tests in which the degree of response produced by exposure to an effluent is being measured. Both approaches will be discussed in some detail, for the first also some original data will be presented.

Evaluation and generalization of field experiences.

External influences on an ecosystem might be detected by their effects upon the functioning and/or structure of the biological components. However, generalization of observed effects is hampered by the naturally occurring differences in functioning and structure among (communities of) organisms due to distribution and ecosystem development patterns. These patterns are primarily determined by master factors as, for instance, seasonality, current velocity, salinity, morphology, acidity and sediment composition.

**Figure 2. Relation between temporal and spatial scales of the effects on the various biological components, compared to the sampling programme and site.**

---

**Biological assessment**

An extensive study from 1985 to 1987 included a wide variety of localities throughout The Netherlands (> 60), selected on the basis of type of sewer system and receiving water. At each locality three sampling sites have been selected: site A: in the immediate vicinity of the overflow; site B at some distance of the overflow, but within its sphere of influence; site C: a reference site in the same type of water, close to, but not influenced by the overflow. As effects of overflows on biological objects are expected to be reflected in different time scales (Figure 2), depending on the type of organism studied and their habitat (free-floating or planktonic versus rooted or benthic), the sampling programmes included:

- **Programme S (short):** immediately after an overflow event;
- **Programme M (medium):** one to four days later;
- **Programme L (long):** one or two weeks after an overflow event;
- **Programme B (background):** at least one month after an overflow event.

Depending on morphology and other characteristics of the sampling sites (basis selection) and on the lifecycle of the organisms, the following biological objects have been studied: phytoplankton (S & M), microfauna (zooplankton: S, M & L and zoobenthos: L), epiphytic diatoms (B), macro-invertebrates (L & B) and macrofauna (B).

**Figure 3a (left). Ordination diagram of sampling sites A and C on the basis of macro-invertebrate species composition and abundance.**

**Figure 3b (right). Ordination diagram of sampling sites A, B and C on the basis of macro-invertebrate species composition and abundance.**

Clustering (TWINSPAN) and ordination (DECORANA) of the sampling sites on the basis of similarity in species composition and abundance proved to be useful in visualizing the effects of overflows on the biological objects mentioned above. Only the results of the macro-invertebrates investigations are used here to illustrate this. Figure 3a shows a diagram of the A and C sampling sites in (semi-)stagnant waters, ordinated on the basis of their macrofauna species composition and abundance. In contrast to expectations, the A and C sites are distributed randomly throughout the plot, indicating that the ordination of the sites (including the B sites) is not determined primarily by the presence of an overflow. However, in Figure 3b it can be seen that ordination of all the sites is largely determined by the size of the receiving water body (first principal axis) and the sediment composition (second principal axis). So the influence of overflows on macro-invertebrates is only of secondary importance. As site-specific conditions (morphometry and sediment composition) are so important, harmful effects can only be detected when receiving waters are already subdivided in different types.
In general, the smaller or more isolated the water body, the more pronounced differences in species composition between the sites are. In large closed waters organic and heavy metals etc. accumulate in the deeper parts and there the first effects will be found. As toxic effects are not released or of secondary importance, traditional biological assessment methods can also be used (Pantel and Buck, 1955; Woodwiss, 1964; Moller Pillot, 1971; Sládecek, 1973). Gardeniers and Tolkamp, 1976). These methods are based upon (groups of) species indicating the saprobic level, traditionally associated with measurements of the D.O., biological oxygen level and ammonium.

After an overflow event restoration of water quality is (partly) possible, particularly in the water phase. Recovery will largely depend on inoculation of the water body with species. If the water body is isolated and difficult access inoculation is prevented. Soil conditions will deteriorate further after each new event. Due to mineralization of organic matter oxygen consumption will increase and heavy metals accumulate. As indicated previously, the different biological components in an ecosystem will react differently upon external changes. To illustrate the differences in reaction (time) upon overflow events one type of surface water has been selected to study the effects of overflows upon the different biological components of the system. A pond frequently disturbed by overflows (Loenen) has been studied intensively during one year (1984) using a fortnightly sampling programme. A non-disturbed pond in the neighbourhood has been used as reference (Apeldoorn). Results of these investigations have been published by Willemse and Cuppen (1986) and by Rolijakers and Ebbeng (1986). Effects on macro-invertebrates were not pronounced. Important effects were physically induced, e.g. passive transportation by the incoming water masses (macro-invertebrates, plankton, benthic organisms) or changes in turbidity (algae). The recurrent overflows in the detention pond prevented maturation of the ecosystem and community structure was minimal. The communities of epiphytic diatoms particularly showed an architecture accommodate to the existence of flushing, whereas the epiphytic diatom communities in the reference pond showed a much more pronounced architecture. Discrimination on saprobic degree was possible, but fluctuations through time were barely detected (Figure 4: top). Phytoplankton reacted mainly upon changes in light climate as nutrients causing colloidal matter was flushed and the water mass became very transparent for a few days. Due to the higher irradiance level phytoplankton biomass increased and phytoplankton species were characterized by their high turnover rate. Phytoplankton was not suitable to indicate saprobic degrees (Figure 4: middle). Zooplankton clearly reacted on water movements and input of organic matter (Figure 4: bottom). In the case of coelocentasp and macro-invertebrates the importance of inoculation from the shore vegetation (a temporary refuge) was clearly indicated. From the above it follows that tests on organisms living in the water phase should primarily be acute toxicity tests.

On the basis of the above-mentioned studies a suitable biological component can be selected for field observations, depending on the type of water and conditions. Also these studies show objects, which are suitable indicator organisms that can be used in laboratory studies among bio-assays are most popular. In future, however, more attention should be paid to larger scale laboratory experiments, in which natural situations are reflected better and more complex communities can be studied (Kersting, 1984a, b). Enclosure experiments proved in several other situations to be an excellent tool in testing the effects of pollutants under natural conditions.
Although toxicologists generally prefer flow-through test conditions, a static test may be more representative for overflows from sewer systems. In such tests the solution (test medium) is added to the dilute effluent from the exposure system, which the test organisms are added without any change of water during the test. This exposure system allows degradation, build up of metabolites, consumption, volatilization and consumption of oxygen to occur. All this is more realistic, but also more difficult to document and standardize. Of particular interest is the probability of synergistic effects with specific additives. For instance, the LC50 for 96 h exposure of rainbow trout has been shown to decrease with decreasing DO concentration (Thurston, 1981, in Russo, 1985).

For CSO’s the recurrence time is generally long. This means that the fate of constituents with a short life cycle is not very interesting and mainly higher organisms should be tested. For isolated systems where recolonization is a problem this is not necessarily true. For storm water, discharges the recurrence time is much shorter, hence short living organisms may become important; certainly as they serve also as a food source (algae). In this case of algae stimulation of growth may occur as well as a consequence of nutrient additions. A bio-assay may then indicate the potential for growth stimulation of algae stimulation of growth may occur as well as a consequence of nutrient.

The assumption is that the ratio between the chronic test values (MATC, LC50) to Lowest Observed Effect Concentration (LOEC) used to define the AF value. The value of AF for complex effluents is much more independent of AF for complex effluents is much more common than for single species. For the toxicologist, the ratio between the chronic test values (MATC, NOEC and LOEC) and the acute toxicity value LC50 is relatively independent of the species tested for a specific chemical (Rand and Petrecci, 1985). As a consequence the tests need not to be performed with long living organisms for which the test period may be as long as one year. Instead the tests can be made with for instance Daphnia-spezies to assess the AF value, after which only an acute test with other relevant species is needed. For application to benthic organisms exposed to quite different substrates than Daphnia this comparison fails in principle. Furthermore no information regarding the independency of AF for complex effluents is known to the authors.

Extrapolation of Early Life Stage tests to MATC has proven to be successful in many cases (McKim, 1985). So extrapolation of acute tests to chronic effects is practicable and realistic without any change of water during the test. This exposure system allows degradation, build up of metabolites, consumption, volatilization and consumption of oxygen to occur. All this is more realistic, but also more difficult to document and standardize. Of particular interest is the probability of synergistic effects with specific additives. For instance, the LC50 for 96 h exposure of rainbow trout has been shown to decrease with decreasing DO concentration (Thurston, 1981, in Russo, 1985).


